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Title of the Invention: DC-DRIVEN PLANAR DISPLAY DEVICE
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Specification

[Title of the Invention] DC-DRIVEN PLANAR DISPLAY DEVICE

[Claim]
[Claim 1] A DC-driven planar display device, comprising a liquid or solid for display, optical characteristics of which are changed by a DC current, provided in a sealed state in a space between electrodes opposed to each other, the DC-driven planar display device being characterized in that an insulating layer is provided on a surface of at least one of the electrodes opposed to each other, and a maximum voltage value applied to the insulating layer is smaller than the product of a dielectric breakdown strength and a thickness of the insulating layer.

[Detailed Description of the Invention]
[0001]
[Field of the Invention] The present invention relates to a DC-driven planar display device such as an electrophoresis display device, in which a surface of an electrode in contact with a display liquid is coated with an insulating material so as to block a DC current, and thus the quality

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change of the display liquid caused by transfer of charges between the display liquid and the electrode is prevented.

[0002]
[Prior Art and its Problems] As shown in Figure 4, a DC-driven planar display device such as an electrophoresis display device includes two transparent substrates 1 and 3 which are formed of glass or the like and respectively have electrodes 2 and 4 formed on surfaces thereof opposed to each other. The transparent substrates 1 and 3 are opposed to each other with a prescribed distance kept therebetween. A display liquid 5 including a dispersion medium colored with a dye and pigment particles is sealed in a space between the substrates 1 and 3. A DC voltage is applied to the electrodes 2 and 4 opposed to each other so as to generate a DC electric field in the display liquid 5 and move the pigment particles thus charged. Thus, a desired display is realized while changing the distribution of the pigment particles.

[0003] However, the application of the DC voltage generates an electric field in the display liquid 5 and also generates a DC current in a circuit connecting the display liquid 5, the electrode 2 and 4, and a power supply. The specific resistance of the display liquid 5 used in an electrophoresis display device is usually $10^8 \Omega\cdot cm$ or more, which is relatively high, and the DC current thereof is several microamperes per square centimeters, which is relatively small. The influence of the DC current on the reliability regarding the long life of the device is quite significant.

[0004] In other words, an inflow of electrons from outside the display liquid 5 or outflow induces the oxidation and reduction of the display liquid, which causes instability,

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specific to DC driving display devices. The instability is caused due to factors such as, for example: a display change caused by a quality change in the dye; or a quality change of the surfactant used for dispersing the electrophoretic particles; extinction of the electrode caused by dissolution of the electrode components into the display liquid; or a combination of these obstacles.

[0005] In a conventional electrophoresis display device, various attempts have been made to improve the reliability during the term during which the device can be practically usable. Such attempts include, for example, increasing the specific resistance of the display liquid to reduce the DC current so that the life of the device is extended; and adopting a voltage application system which avoids superimposing of DC voltages as described in Japanese Patent Application No. 2-8875 filed by the Applicant of the present application. However, such means cannot be considered to be provide a fundamental solution and are not sufficient. According to such means, for example, the life is different based on the lot of the material; or the usable dyes, surfactants and the usable amounts are restricted, and thus the display quality itself is deteriorated.

[0006] In the case of, for example, AC-driven display devices such as liquid crystal display devices and AC-driven plasma display devices, a dielectric film is provided on a surface of the electrode in order to prevent deterioration of the display and inflow of charges into the electrode as well as to achieve other aims. In the case of a DC-driven display device, such a system is not adopted because a continuous application of a DC voltage for maintaining the display accumulates the charges in the dielectric film, which prevents effective application of the electric field on the

display medium or causes dielectric breakdown of the dielectric film.

[0007]
[Objective and Structure of the Invention] The present invention is to provide a DC-driven planar display device for preventing quality change of a display liquid caused by transfer of the charges between the display liquid and the electrode, by blocking of a DC current by coating a surface of the electrode in contact with the display liquid with an insulating material.

[0008] In order to achieve the above-described objective, a DC-driven planar display device according to the present invention includes a liquid or solid for display, the optical characteristics of which are changed by a DC current, provided in a sealed state in a space between electrodes opposed to each other. The DC-driven planar display device includes an insulating layer provided on a surface of at least one of the electrodes which are opposed to each other, and is structured so that the maximum voltage value applied to the insulating layer is smaller than the product of a dielectric breakdown strength and a thickness of the insulating layer.

[0009]
[Examples] Figure 1 is a conceptual enlarged cross-sectional view of an important part of a DC-driven planar display device structured in accordance with the present invention. In the Figure, identical reference numerals as those in Figure 4 represent identical elements. In Figure 1, electrodes 2 and 4, required for display, are formed of a conductive material such as, for example, indium tin oxide and provided on surfaces of transparent substrates 1 and 3 which are op-

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posed to each other. The electrodes 2 and 4 are connected to an external power supply outside the transparent substrates 1 and 3 through leads not shown.

[0010] The electrodes 2 and 4 and parts of the leads are coated with insulating layers 6 and 7 which are formed separately in accordance with the present invention. Usable as the insulating materials 6 and 7 are, for example, insulating polymers such as polyethylene, polyimide, ethylene tetrafluoride and the like; and insulating metal oxides such as silicon oxide, barium titanate, titanium oxide and the like. The insulating layers 6 and 7 can be appropriately formed by a usual film formation method such as coating, printing, LB film formation, deposition, sputtering or the like. An electrophoresis display device as a DC-driven planar display device is completed by putting the display liquid 5 between the electrodes 2 and 4, provided with the insulating layers 6 and 7 in a conventional manner, and sealing the periphery of the transparent substrates 1 and 3 with an adhesive.

[0011] When a DC voltage is applied to the electrodes 2 and 4 of the above-described display device, the insulating layers 6 and 7 formed on the surfaces of the electrodes 2 and 4 act as an equivalent capacitance connected in series to an equivalent resistance of the display liquid 5 and thus suppress inflow of DC current components from the display liquid 5 to the electrodes 2 and 4 and outflow.

[0012] In other words, when the electrodes 2 and 4 are coated with the insulating layers 6 and 7 formed of a highly dielectric material, the film thickness is made sufficiently small to make the equivalent series capacitance sufficiently large, so as to make the time constant determined by the

equivalent series capacitance and the specific resistance of the display liquid 5 sufficiently larger than the response time of the display device, the voltage applied to the display device within the response time can be maintained to be constant and substantially equal to the applied voltage. Moreover, since the display liquid 5 is not in contact with the electrodes 2 and 4, the above-described outflow of the charges can be restricted.

[0013] The equivalent capacitance can be set to be large. However, needless to say, when operating voltage pulses having the same polarity are continuously applied, the coating film is charged and thus the level of the voltage applied to the display device is reduced. As a result, the display function of the display device cannot be maintained.

[0014] An electrophoresis display device according to the present invention has a memory function which is perfect for display and thus does not require application of voltages of the same polarity for maintaining the display. Therefore, application of the pulses of the same polarity can be restricted as in the case of the technology described in Japanese Patent Application No. 2-8875. Accordingly, the present invention can be carried out in consideration of the response time of the display; and the dielectric constant, thickness and the withstand voltage of the coating films formed of the insulating layers 6 and 7. Thus, the electrochemical reaction of the display device can be restricted. Hereinafter, the case in which the above-described insulating layer is formed on one of the electrodes will be described.

[0015] This type or similar types of insulating layers or protection layers of an insulating substance formed on elec-

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trode surfaces are known in the case of AC-driven display devices. An insulating layer according to the present invention, which is required to have capabilities specific to DC-driven display devices, is essentially different from the conventional insulating layers. In other words, insulating layers in the AC-driven display devices include, for example, a polymer alignment layer used in liquid crystal display devices and a magnesium oxide protection layer used in AC plasma display devices. The former is used for alignment, and the latter has a function as an ion impact alleviator or a secondary electron supplying layer, which are different from formation of a capacitance for inhibiting a DC current. The withstand voltage V_{IX} required for a conventional protection layer is expressed by the following expression and is different from that of the insulating layer according to the present invention.

$$V_{IX} = \frac{\varepsilon_0 / d_0}{\varepsilon_{IX}/d_{IX} + \varepsilon_0 / d_0} \times E$$

where E is the peak value of the applied AC voltage, ε_{IX} is the dielectric constant of the protection layer, d_{IX} is the thickness of the protection layer, ε_0 is the dielectric constant of the display liquid, and d_0 is the thickness of the display liquid.

[0016] The voltages applied to the insulating layer and the display liquid 5 for generating a display by applying the voltages to the display device according to the present invention can be found by obtaining a transient response resolution with the equivalent circuit shown in Figure 2. When a display pulse having a voltage E and a pulse width t_{PE} which is required for display is applied in the state of zero initial charge, voltage Vp applied to the display liquid 5 is expressed by:

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$$V_P = \frac{C_1 E}{C_1 + C_2} \exp\left(-\frac{C_1 + C_2}{r C1C2} t\right) + \frac{C_1 E}{C_1 + C_2} \exp\left(-\frac{1}{R(C_1 + C_2)} t\right)$$

where C_1 is an equivalent capacitance of the insulating layer, C_2 is an equivalent capacitance of the display device, R is an equivalent resistance of the display liquid 5, r is an intra-power supply resistance and wire equivalent resistance, and E and -E are each an operating voltage pulse.

[0017] In the above expression, when r based on the wire and intra-power supply resistance is small, the first term of the expression is a transient term corresponding to the boosting period from a voltage of zero and thus becomes a negligible value within a short time period. Consequently, the value of the second term is applied to the display liquid 5. In the case where the C_1, i.e., the capacitance of the insulating layer is designed to be large so that $R(C_1+C_2)$ is sufficiently larger than the pulse width t_{PE} required for display, Vp is substantially $C_1E/(C_1+C_2)$ where $C_1 \gg C_2$. Accordingly, Vp=E. This value of Vp is equal to that in the case where no insulating layer is provided. Characteristically, unlike the case with no insulating layer, the pigment particles in the display liquid and electrons and ions in the solvent do not provide the electrode with charges, and only the spatial positions thereof are changed without the quality thereof being changed by oxidation or reduction reaction.

[0018] A voltage V_I applied on the insulating layer is determined in a similar manner, and the maximum value thereof is:

$$V_I = E - \frac{C_1 E}{C_1 + C_2} \exp\left(-\frac{1}{R(C_1 + C_2)} t_{PE}\right)$$

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The insulating layer structured according to the present invention needs to be designed to have a withstand voltage equal to or greater than V_I.

[0019] The expression can be represented as follows using ~~the area S of the insulating layer, the thickness d_1 of the~~ insulating layer, the dielectric constant ε_1 of the insulating layer, the area S of the display liquid, the thickness d_0 of the display liquid, the dielectric constant ε_0 of the display liquid, and the specific resistance R_0 of the display liquid.

$$V_I = E - E \times \frac{d_0 \cdot \varepsilon_1}{d_0 \cdot \varepsilon_1 + d_1 \cdot \varepsilon_0} \exp\left(-\frac{t_{PI}}{(\varepsilon_0 + \varepsilon_1 \cdot d_0 / d_1) R_0}\right)$$

Namely, the dielectric breakdown strength of the insulating layer$\times d_1 > V_I$.

[0020] When, for example, an SiO_2 insulating layer having $\varepsilon_1=4\times 0.0885\times 10^{-12}$(F/cm) and $d_1=0.1\times 10^{-4}$(cm) is provided in an electrophoresis display device having $d_0=50\times 10^{-4}$(cm), $\varepsilon_0=3\times 0.0885\times 10^{-12}$(F/cm), $R_0=10^{11}$($\Omega\cdot$cm) and a response speed of 100×10^{-3}(sec.), V_I is about -0.28 V. By contrast, the dielectric breakdown strength of the insulating material is about 30 kV/mm, and the insulation strength of the insulating layer is 3 V, which are sufficient to withstand V_I. The constants regarding the electrophoresis display device calculated above by way of trial are average constants of trial products produced so far. Even materials having constants different from the above constants can be selected in consideration of the dielectric constant and dielectric breakdown strength of the insulating layer to be formed.

[0021] Hereinafter, voltages of various parts obtained when a pause pulse having a voltage of zero is applied after the

above-described display pulse is applied will be described. Where t is the time period after the applied voltage is made zero, the voltage Vp applied to the display liquid is

$$V_{P-} = -\frac{C_1 E}{C_1 + C_2} \left(1 - \exp\left(-\frac{1}{R(C_1 + C_2)} t_{PE}\right)\right) \exp\left(-\frac{1}{R(C_1 + C_2)} t\right)$$

Since C_1 is set so that $R(C_1+C_2)$ is sufficiently larger than t_{PE}, the absolute value of Vp_- is too small to have any influence on the display. When R_S which is larger than R is set to restrict the charge inflow from C_1 to C_2 in order to alleviate the application of the opposite polarity voltage on the display device, as shown in Figure 3, the value of Vp_- can be further reduced.

[0022] The display device including the above-described insulating layer is driven effectively utilizing the memory for display so that the superimposing application of the voltage pulses having the same polarity, which is described in Japanese Patent Application No. 2-8875, is prevented and thus the excessive charging of the insulating layer is prevented. Accordingly, an element which has been once displayed is supplied with a voltage having an opposite polarity for discharging the charges of the insulating layer, and thus the voltage applied to the insulating layer does not exceed the value of V_I described above.

[0023] In the above, required conditions for the insulating layer and specific examples of the driving methods for a DC-driven planar display device including an insulating layer on either one of the electrodes 2 and 4 are described. The counter electrode can also be coated with a similar insulating layer, and this is preferable for improvement of performance, which is an objective of the present invention.

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[0024] An electrophoresis display device is described in the above as an example of DC-driven planar display devices, but the present invention is also applicable to other types of DC-driven planar display devices having a memory function such as, for example, an electrochromic display device.

[Effect of the Invention] A DC-driven planar display device according to the present invention, as can be apparent from the above description, coats a surface of an electrode in contact with the display liquid with an insulating material to block the DC current. Thus, quality change caused by transfer of charges between the display liquid and the electrode, i.e., the quality change of the display liquid caused by oxidation and reduction of ions in the display liquid can be prevented.

[0026] Accordingly, the color change of the dye, deterioration of the dispersion state, change of the electrophoresis characteristics of the dispersion particles, and the like can be prevented.

[Brief Description of the Drawings]
[Figure 1] A conceptual cross-sectional view of a DC-driven planar display device structured according to one example of the present invention.

[Figure 2] An equivalent circuit diagram in the case where an insulating layer is formed on one of the electrodes in Figure 1.

[Figure 3] An equivalent circuit diagram in the case where an external resistor is provided in Figure 2.

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[Figure 4] A conceptual enlarged cross-sectional view of an important part of a conventional electrophoresis display device.

[Description of Reference Numerals]

1 Transparent substrate
2 Electrode
3 Transparent substrate
4 Electrode
5 Display liquid
6 Insulating layer
7 Insulating layer

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[Abstract]
[Objective] To provide a DC-driven planar display device, such an electrophoresis display device, for preventing a quality change of a display liquid caused by transfer of charges between the display liquid and an electrode, by blocking a DC current by coating a surface of the electrode in contact with the display liquid with an insulating material.

[Structure] A planar display device including a liquid or solid, the optical characteristics of which are changed by a DC current, provided in a sealed state between electrodes opposed to each other. The planar display device includes an insulating layer formed on a surface of at least one of the electrodes which are opposed to each other, and is structured so that the maximum value of the voltage applied to the insulating layer is larger than the product of the dielectric breakdown strength and the thickness of the insulating layer.